CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA 91125

RESEARCH REPORT

1983 - 1985

ENVIRONMENTAL QUALITY LABORATORY

California Institute of Technology

Pasadena, California 91125

EQL Memo No. 25

March 1986

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AN INTRODUCTION TO EQL

The Environmental Quality Laboratory at Caltech is a center for research on large scale systems problems of natural resources and environmental quality. The principal areas of investigation at EQL are:

1. Air quality management.
2. Water resources and water quality management.
3. Control of hazardous substances in the environment.
4. Energy policy, including regulation, conservation and energy-environment trade-offs.
5. Resources policy (other than energy); residuals management.

EQL research includes technical assessments, computer modeling, studies of environmental control options, policy analyses, and research on important components of the large scale systems. Field work is also undertaken at EQL, some in collaboration with other organizations, to provide critical data needed for evaluation of systems concepts and models.

EQL's objectives are as follows:

1. To do systematic studies of environmental and resources problems. The results of these studies, including the clarification of policy alternatives, are communicated to decision-makers in government and industry, to the research community, and to the public. As an organization, EQL

refrains from advocating particular policies, but seeks to point out the implications of the various policy alternatives.

2. To contribute to the education and training of people in these areas through involvement of pre-doctoral students, post-doctoral fellows, and visiting faculty members in EQL activities. This educational effort is just as important as the results of the studies themselves, and should make lasting contributions to the nation's ability to solve its environmental and resources problems.

The work at EQL goes beyond the usual academic research in that it tries to organize and develop the knowledge necessary to clarify society's alternatives by integrating relevant disciplines. EQL works on solving problems of specific localities when there is a strong element of public interest or educational value, or the concepts and results are applicable to other places.

The research of EQL is done under the supervision of faculty members in Environmental Engineering Science, Chemical Engineering, and Social Science.

This research report covers the period from October 1983 through September 1985.

ENVIRONMENTAL QUALITY LABORATORY

PROFESSIONAL STAFF, 1983-85

Norman H. Brooks, Director
James J. Morgan, Acting Director 1984-85.

		Dates*
Scott D. Boyce	Research Fellow in Environmental Engineering Science	2/81-2/84
	Senior Research Engineer	4/84-8/84
Norman H. Brooks	James Irvine Professor of Environmental and Civil Engineering; Director, EQL	
Glen R. Cass	Associate Professor of Environmental Engineering	
Sin Chung Cheung	Research Engineer	12/82-10/84
Gabriel T. Csanady	Visiting Associate in Environmental Engineering Science	2/84-3/84
Jeffrey A. Dubin	Assistant Professor of Economics	
Richard C. Flagan	Professor of Environmental Engineering Science and Mechanical Engineering	
Michael R. Hoffmann	Professor of Environmental Engineering Science	
Vit Klemes	Visiting Associate in Environmental Engineering Science	1/84-3/84
Robert C. Y. Koh	Senior Research Associate in Environmental Engineering Science	
Lode Li	Research Fellow in Economics	9/84-8/85
E. John List	Professor of Environmental Engineering Science	

*Month and year of residence at EQL are shown only for those who were not in residence for the whole period 10/83-9/85.

Kenneth F. McCue	Scientist	
James J. Morgan	Professor of Environmental Engineering Science; Vice President for Student Affairs	
Roger G. Noll	Institute Professor of Social Sciences	Until 8/84
R. Talbot Page	Senior Research Associate in Economics	
Charles R. Plott	Professor of Economics	
James P. Quirk	Professor of Economics	
Geoffrey S. Rothwell	Research Fellow in Economics	8/85-
Armistead G. Russell	Senior Research Engineer	1/85-9/85
George H. Schmid	Visiting Associate in Environmental Engineering Science	9/83-8/84
John H. Seinfeld	Louis E. Nohl Professor and Executive Officer, Chemical Engineering	
Fredrick H. Shair	Professor of Chemical Engineering	
Paul A. Solomon	Scientist	12/84-
Paul Whitmore	Scientist	11/84-
Louis L. Wilde	Professor of Economics	

GRADUATE STUDENTS SUPPORTED#

BY EQL GRANTS AND CONTRACTS

1983-84		1984-85	
Name	Option*	Name	Option*
Anilkumar, A. V.	ME	Anilkumar, A. V.	ME
Arnold, Robert G.	EES	Bassett, Mark	ChE
Bales, Roger	EES	Cohen, Mark	ChE
Banks, Jeffrey	SS	Collett, Jeffrey L.	EES
Bassett, Mark	ChE	Fuhs-Huff, Susan E.	ME
Collett, Jeffrey L.	EES	Georgopoulos, Panos G.	ChE
Conklin, Martha H.	EES	Gillroy, John	SS
DiChristina, Thomas J.	EES	Gray, H. Andrew	EES
Faust, Bruce C.	EES	Guler, Kemal	SS
Fort, Rodney	SS	Hildemann, Lynn	EES
Fuhs-Huff, Susan E.	ME	James, David E.	EES
Georgopoulos, Panos G.	ChE	Johnson, B. Ellen	EES
Gillroy, John	SS	Jones, Carol L.	ChE
Gray, H. Andrew	EES	Kreidenweis, Sonya M.	ChE
Hannoun, Imad	CE	Larson, Susan M.	EES
Hildemann, Lynn	EES	Liang, Liyuan	EES
Ho, Alex W.K.	EES	Nazaroff, William W.	EES
Houseworth, James E.	EES	Paterson, Andrew S.	EES
Hunts, Susan	EES	Pegram, William	SS
Jacob, Daniel J.	EES	Pilinis, Christodoulos	EES
Johnson, B. Ellen	EES	Russell, Armistead G.	ME
Larson, Susan M.	EES	Shafer, Toby B.	ChE
Leone, Joseph	ChE	Stern, Jennifer	ChE
Liang, Liyuan	EES	Wang, Rueen-Fang T.	EES
Mattock, Michael	ChE	Warren, Dale	ChE
McCubbins, Mathew	SS		
Pegram, William	SS		
Pilinis, Christodoulos	EES		
Russell, Armistead G.	ME		
Selinger, Steven	SS		
Shafer, Toby B.	ChE		
Valioulis, Iraklis	EES		
Wang, Rueen-Fang T.	EES		
Yin, Fangdong	ChE		

* CE = Civil Engineering
ChE = Chemical Engineering
EES = Environmental Engineering Science
ME = Mechanical Engineering
SS = Social Science

In some cases only partial support is provided by EQL.

DOCTORAL THESES COMPLETED

1983-85

Name	Field	Faculty Adviser
James Evan Houseworth	EES	N. H. Brooks
Longitudinal Dispersion in Nonuniform Isotropic Porous Media		
Roger C. Bales	EES	J. J. Morgan
Surface Chemical and Physical Behavior of Chrysotile Asbestos in Natural Waters and Water Treatment		
Rodney D. Fort	SS	R. Noll
Theory and Practice in the Analysis of Commodity Futures Price Distribution		
Armistead G. Russell	ME	G. R. Cass
Formation and Control of Atmospheric Aerosol Nitrate and Nitric Acid		
John Martin Gillroy*	SS	B. Barry
Political Theory and Environmental Risk Regulation: A Kantian Foundation for Public Policy Choice		
Joseph A. Leone	ChE	J. H. Seinfeld
Studies in Photochemical Smog Chemistry: I. Atmospheric Chemistry of Toulene, II. Analysis of Chemical Reaction Mechanisms for Photochemical Smog		
Mark E. Bassett	ChE	J. H. Seinfeld
Mathematical Modeling of Atmospheric Aerosol Equilibria and Dynamics		

*University of Chicago

SPONSORS AND DONORS

The staff and students of EQL gratefully acknowledge the support of the following research sponsors and donors for fiscal years 1984 and 1985:

Government Sponsored Projects

Local

County Sanitation Districts of Orange County
South Coast Air Quality Management District

State

California Air Resources Board

Federal

Environmental Protection Agency
National Oceanic and Atmospheric Administration
National Science Foundation

Private Sources

Discretionary Funds - General

Bechtel Foundation
General Electric Foundation
General Motors
Gilloon Foundation
Hewlett Foundation
Andrew W. Mellon Foundation
Southern California Edison Co.
Texaco

Discretionary Funds - Specific Program Areas

Atlantic Richfield
Exxon Education Foundation
Andrew W. Mellon Foundation
Unocal

Sponsored Research Projects

J. Paul Getty Conservation Institute

SUMMARIES OF EQL RESEARCH PROJECTS

1983-85

A. AIR QUALITY MANAGEMENT

CONTROL OF ATMOSPHERIC AEROSOL NITRATE AND NITRIC ACID CONCENTRATIONS

Investigators: Armistead G. Russell,* Lynn Hildemann,* Gregory J. McRae, Glen R. Cass

Support: State of California Air Resources Board and gifts to the Environmental Quality

A mathematical model for the formation of atmospheric nitric acid and aerosol nitrate has been developed and employed to study the effect of emission controls. Based on a Lagrangian formulation of the atmospheric diffusion equation, the model computes nitric acid concentrations from a description of daytime photochemical reactions and nighttime reactions involving NO_3 and N_2O_5. Ammonium nitrate formation is computed at thermodynamic equilibrium between HNO_3 and NH_3, and heterogeneous reactions between HNO_3 and preexisting aerosol are considered. The accuracy of the air quality model's predictions has been verified by comparison to O_3, NO_2, HNO_3, NH_3, aerosol nitrate, and PAN measurements made for this purpose in California's South Coast Air Basin.

Examination of emission control alternatives shows that reduction in NO_x emissions yields a nearly proportional decrease in total inorganic nitrate levels (HNO_3 + aerosol nitrates). Reduction in ammonia emissions suppresses aerosol nitrate formation, resulting in higher nitric acid levels. Control of organic species emissions by the amounts expected in Los Angeles in future years causes a partial shift away from PAN formation toward greater production of nitric acid. Emission control strategies can be formulated that include a combination of controls on NO_x, organic gases, and NH_3 emissions that will achieve a greater reduction in HNO_3, aerosol nitrate, and O_3 levels than a strategy predicated on control of only a single precursor species.

Publications:

A. G. Russell, G. R. Cass, "Acquisition of Regional Air Quality Model Validation Data for Nitrate, Sulfate, Ammonium Ion and Their Precursors," Atmospheric Environment, v. 18, 1984, pp. 1815-1827.

*Graduate Student

L. M. Hildemann, A. G. Russell, G. R. Cass, "Ammonia and Nitric Acid Concentrations in Equilibrium with Atmospheric Aerosols: Experiment vs. Theory," Atmospheric Environment, v. 18, 1984, pp. 1737-1750.

A. G. Russell, G. J. McRae, G. R. Cass, "The Dynamics of Nitric Acid Production and the Fate of Nitrogen Oxides," Atmospheric Environment, v. 19, 1985, pp. 893-903.

A. G. Russell, G. R. Cass, "Verification of a Mathematical Model for Aerosol Nitrate and Nitric Acid Formation, and Its Use for Control Measure Evaluation," Atmospheric Environment, 1986 (forthcoming).

A. G. Russell, Formation and Control of Atmospheric Aerosol Nitrate and Nitric Acid, Ph.D. Thesis, California Institute of Technology, 1985.

CHARACTERIZATION AND CONTROL OF ATMOSPHERIC CARBON PARTICLE CONCENTRATIONS

Investigators: H. Andrew Gray,* Shohreh Gharib, James Huntzicker,** Glen R. Cass

Support: State of California Air Resources Board

Light absorption by elemental carbon particles plays a major role in urban visibility problems. A multi-year study is underway designed to identify efficient approaches for control of atmospheric carbon particle concentrations. An eleven-station air monitoring network was constructed and operated in the Los Angeles area to define current elemental and organic carbon particle concentrations. A mathematical model of the relationship between aerosol carbon emission sources and resultant regional air quality has been assembled and tested against observations made during the ambient sampling program. Methods have been developed to identify the most attractive emission control strategies that could be used to achieve improved aerosol carbon air quality.

Publications:

H. A. Gray, G. R. Cass, J. J. Huntzicker, E. K. Heyerdahl, J. A. Rau, "Elemental and Organic Carbon Particle Concentrations: A Long-Term Perspective," Science of the Total Environment, v. 36, 1984, pp. 17-25.

G. R. Cass, M. H. Conklin, J. J. Shah, J. Huntzicker, "Elemental Carbon Concentrations: Estimation of an Historical Data Base," Atmospheric Environment, v. 18, 1984, pp. 153-162.

H. A. Gray, G. R. Cass, J. J. Huntzicker, E. K. Heyerdahl, J. A. Rau, "Characteristics of Atmospheric Organic and Elemental Carbon Particle Concentrations in Los Angeles," Environmental Science and Technology, 1986 (forthcoming).

*Graduate Student
**Chairman, Department of Environmental Sciences, Oregon Graduate Center

ACQUISITION OF ACID VAPOR AND AEROSOL CONCENTRATION DATA IN THE SOUTH COAST AIR BASIN

Investigators: Paul Solomon, Theresa Fall, Glen R. Cass

Support: State of California Air Resources Board and the South Coast Air Quality Management District

A field experiment to measure the spatial and temporal concentration distribution of gas phase acids (HNO_3, HCl, HBr, HF), weak organic acids, and related particulate phase species in the South Coast Air Basin is underway at present. The ambient sampling program is being conducted at nine locations in the air basin that surrounds Los Angeles during a one-year period. The concentration and chemical composition of airborne particles in sizes below 10 μm in diameter is being defined for use in the design of emission control programs intended to achieve new state and federal PM10 air quality standards. The data base is designed so that the removal routes for atmospheric acids can be determined, including: ground level dry deposition, advection out of the air basin, and conversion of acid gases to airborne particulate matter that may change the acid-base character of the strong acids originally present in the atmosphere.

This is a preliminary report of work in progress, and as yet no written reports are available for distribution.

CONTROL OF ORGANIC AEROSOL EMISSIONS

Investigators: Lynn Hildemann,* Monica Mazurek,** Bernd Simoneit,** Glen R. Cass

Support: Gifts to the Environmental Quality Laboratory, National Science Foundation

Organic aerosols in the atmosphere are of concern due to their potential as carcinogens and because organic particulate matter accounts for typically 30% of the fine aerosol mass. A study of the relationship between the chemical composition of organic compounds in source emissions and the composition of organics observed in ambient air is underway at present. Particulate emissions from a wide range of major air pollution source types will be collected using a dilution stack sampling system specially constructed to simulate the atmospheric condensation and aging processes normally experienced by a stack plume containing organic air pollutants. Analysis of these samples by high-resolution gas chromatography (GC) and computerized gas chromatography/mass spectrometry (GC/MS) will define the characteristic organic compound signature for each source type. These source signatures then will be compared to the chemical composition of ambient particulate samples collected in the Los Angeles area in order to identify the relative importance of major emission sources that must be controlled if one is to reduce the organic species loading present in the atmospheric aerosol.

This is a preliminary report of work in progress, and as yet no written reports are available for distribution.

*Graduate Student
**College of Oceanography, Oregon State University

MATHEMATICAL MODELING OF CHEMICALLY REACTING PLUMES

Investigators: Panos Georgopoulos, John H. Seinfeld

Support: State of California Air Resources Board

A new comprehensive model for chemically reacting plumes has been developed. The model accounts for the effects of incomplete turbulent macro- and micro-mixing on chemical reactions between plume and ambient constituents. This "turbulent reacting plume model" is modular in nature, allowing for the use of different levels of approximation of the phenomena involved. The core of the model consists of the evolution equations for reaction progress variables appropriate for evolving spatially varying systems. The equations estimate the interaction of mixing and chemical reaction, and require input parameters characterizing internal plume behavior such as relative dispersion and fine scale plume segregation. The model offers the opportunity for calculating the evolution of chemically reacting species in real atmospheric plumes and will be applied to the problem of predicting NO_2 levels downwind of strong point sources of nitric oxide.

Publications:

P. G. Georgopoulos, J. H. Seinfeld, "Instantaneous Concentration Fluctuations in Point Source Plumes," AIChE Journal, 1986 (forthcoming).

P. G. Georgopoulos, J. H. Seinfeld, "Mathematical Modeling of Turbulent Reacting Plumes. I. General Theory and Model Formulation," Atmospheric Environment, 1986 (forthcoming).

P. G. Georgopoulos, J. H. Seinfeld, "Mathematical Modeling of Turbulent Reacting Plumes. II. Application to the $NO-NO_2-O_3$ System," Atmospheric Environment, 1986 (forthcoming).

DEVELOPMENT OF A COMPREHENSIVE ATMOSPHERIC MODEL FOR AIR POLLUTION AEROSOLS

Investigators: Christodoulos Pilinis, John H. Seinfeld

Support: State of California Air Resources Board

Within the next several years, critical and expensive decisions will be made in California and other states concerning the levels of hydrocarbon, NO_x, and perhaps SO_2 control required to progress toward meeting existing and anticipated State and Federal air quality standards for ozone, NO_2, particles less than 10 microns in diameter (PM-10), visibility and reducing acidic deposition. Decisions on how much emission reduction is required to achieve specified improvements in air quality, can only be made based on a model relating emissions to ambient air quality. Prediction of PM-10, fine particles, visibility and acidic species requires a model capable of relating gaseous and particulate emissions to gaseous acidic substances and particulate sulfate, nitrate, organics, and elemental carbon, ammonium-water and metal-and-soil compound concentrations. Under support of the California Air Resources Board, we are currently developing such a model. The airshed submodel will be a computation carried out within each grid cell of the full Caltech photochemical air quality model, updated at each time step akin to the chemical kinetics. The model will include treatment of liquid phase chemistry, the physics influencing the dynamics of particle size distributions, and parameterization of dry deposition.

This is a preliminary report of work in progress, and as yet no written reports are available for distribution.

OPTIMAL STRATEGIES FOR AIR POLLUTION CONTROL

Investigators: Gregory J. McRae, Glen R. Cass, Kenneth McCue

Support: Mellon Foundation, gifts to the Environmental Quality Laboratory

Receptor-oriented air quality models are very simple but accurate and can identify the emission sources contributing to particulate air quality problems based on matching the trace element content of source emissions and atmospheric samples. Pinpointing the combination of pollutant sources responsible for a problem does not automatically shed much light on how to devise the best emission control strategy to improve air quality. In this research, mathematical programming techniques are being developed that will permit receptor models to be used to identify the least costly combination of control devices needed to solve complex regional particulate air quality problems.

Publications:

G. R. Cass, G. J. McRae, "Emissions and Air Quality Relationships for Atmospheric Trace Metals," J. O. Nriagu and C. I. Davidson, Eds., in "Toxic Metals in the Atmosphere," Advances in Environmental Science and Technology, v. 13, Wiley, New York, 1986 (forthcoming).

G. E. Gordon, W. R. Pierson, J. M. Daisey, P. J. Lioy, J. A. Cooper, J. G. Watson, Jr., G. R. Cass, "Considerations for the Design of Source Apportionment Studies," Atmospheric Environment, v. 18, 1984, pp. 1567-1582.

CONSTRUCTION OF A SYNTHETIC IMAGE PROCESSING-BASED VISIBILITY MODEL AND ITS USE FOR THE DESIGN OF STRATEGIES FOR VISIBILITY IMPROVEMENT

Investigators: Susan Larson,* Kenneth McCue, Kevin J. Hussey,** Frederick Luce,** Glen R. Cass

Support: State of California Air Resources Board, Hewlett Foundation, gifts to the Environmental Quality Laboratory

Light scattering and absorption calculations based on pollutant properties measured during intense pollution episodes can be used to add haze to the foreground of clear sky pictures by image processing techniques. The ability of these light scattering and absorption calculations to accurately reproduce the visual effects that occur during smog episodes is being verified by comparing the synthetic smog images to digitized photos of actual high pollution events. The completed visibility model is being used as part of a systematic investigation of emission control strategies that could be used to achieve a deliberate improvement in summer mid-day low visibility conditions in the Los Angeles area.

Publication:

S. M. Larson, G. R. Cass, K. J. Hussey, F. Luce, "Visibility Model Verification by Image Processing Techniques," final report to the California Air Resources Board under agreement A2-077-32, October 1984.

*Graduate Student
**Image Processing Laboratory, Jet Propulsion Laboratory

PROTECTION OF WORKS OF ART FROM DAMAGE DUE TO PHOTOCHEMICAL SMOG

Investigators: Paul M. Whitmore, William Nazaroff,*
Cynthia Shaver Atherton,** Kaitlin Drisko,**
C. Pam DeMoor,** Mark Adams,** Lisa Cummings,**
Christine Tiller,** James R. Druzik,***
Daniel Grosjean,**** Glen R. Cass

Support: J. Paul Getty Conservation Institute, Mellon Foundation, SURF Funds

The fading of pigments is a major hazard to works of art. Recent work in our laboratories has shown that a number of widely used artists' pigments are not ozone-fast and will fade during a 95-day exposure to 0.40 ppm ozone in the absence of light. Alizarin-based watercolors containing 1,2 dihydroxyanthraquinone lake pigments are particularly sensitive to ozone damage, as Japanese woodblock prints tested during this investigation demonstrated. At present, the extent of this ozone hazard to works of art is being assessed through examination of more than 150 organic pigment samples obtained from the Fogg Museum at Harvard. The chemistry of the attack of ozone on artists' pigments is being investigated via GC/MS analysis of the pigments and their reaction products. The distribution of ozone and NO_2 concentrations in the indoor atmosphere of museums in Southern California is being assessed via a series of field experiments. Mathematical models for the behavior of pollutants inside museums and archives are being developed and tested. Strategies for protecting works of art from damage due to air pollutants are being developed, including selection of pollutant-resistant pigments, pigment reformulation, pollutant removal via ventilation system redesign, encapsulation of works of art, and the use of protective binders and coatings.

Publications:

C. L. Shaver, G. R. Cass, J. R. Druzik, "Ozone and the Deterioration of Works of Art," Environmental Science and Technology, v. 17, 1983, pp. 748-752.

K. Drisko, G. R. Cass, J. R. Druzik, "Fading of Artists' Pigments Due to Atmospheric Ozone," Paper 84-83.6, Proceedings of the 77th Annual Meeting of the Air Pollution Control Association, June 24-29, 1984.

*Graduate Student
**Undergraduate Student
***Conservation Scientist, Los Angeles County Museum of Art
****Visiting Associate in Chemical Engineering

B. WATER RESOURCES AND WATER QUALITY

RESEARCH PLAN FOR EXPERIMENTAL DEEP OCEAN SLUDGE DISPOSAL FOR ORANGE COUNTY

Investigators: Norman H. Brooks, Robert C.Y. Koh, Robert G. Arnold*

Support: Orange County Sanitation Districts, National Oceanic and Atmospheric Administration, Andrew W. Mellon Foundation, Hewlett Foundation

Even though the discharge of sewage sludge into the ocean via an outfall is not now permitted, nonetheless the option may in some cases be more desirable than other disposal options (to land or incineration). A previous study by EQL has assessed ocean alternatives for the Southern California area, and this project has developed a research plan to show what could be learned with a full scale experimental sludge discharge of 150 dry tons/day of sludge by the County Sanitation Districts of Orange County into deep water (over 1000 feet). A revision of the original research plan of 1982 is in progress.

National policy for sludge disposal is currently being reviewed by the federal government, especially with regard to permitting ocean disposal of sludge. Congressional approval for this research and demonstration project is still pending (1985).

Publications:

N. H. Brooks, R. G. Arnold, R.C.Y. Koh, G. A. Jackson, W. K. Faisst, "Deep Ocean Disposal of Sewage Sludge Off Orange County, California: A Research Plan," EQL Report No. 21, second edition in preparation (1985).

N. H. Brooks, R. G. Arnold, R.C.Y. Koh, G. A. Jackson, W. K. Faisst, "Deep Ocean Disposal of Sewage Sludge Off Orange County, California: A Research Plan," Proceedings of the 4th International Ocean Disposal Symposium, Plymouth, England, v. 8, Processes Affecting the Movement and Chemical Behavior of Wastes in the Ocean, edited by Wayne V. Burt et al., Wiley-Interscience, 1984.

*Graduate Student

MODELING OF TRANSPORT AND FATE OF POLLUTANTS IN COASTAL WATER

Investigators: Robert C.Y. Koh, Miles Bogle, Siu C. Cheung

Support: National Oceanic and Atsmospheric Administration

This study seeks to develop models for the estimation of transport and fate of pollutants from ocean wastewater outfalls. The overall transport phenomena, which combine to determine the physical fate of the pollutants, consists of several phases: (i) initial mixing which occurs in a time scale of minutes and a distance scale of a few kilometers; (ii) advective transport by ocean currents which occurs in a time scale of hours to a few days; and (iii) sedimentation of particles, which contain much of the hazardous substances in wastewater.

Two models are developed. One is a state of the art model for the nearfield mixing processes. The second is a model for the advective transport and particulate sedimentation. Actual current meter data coupled with detailed local bathymetry are used to deduce both the deterministic and statistical aspects of the advective transport parameters for specific sites. These are then utilized via Monte Carlo simulation techniques to derive transport and depositional probabilities.

Publications:

R.C.Y. Koh, "Mixing Model for Ocean Wastewater Outfalls," Report to NOAA, Environmental Quality Laboratory, California Institute of Technology, February 1982.

R.C.Y. Koh, "Wastewater Field Thickness and Initial Dilution," Journal of the Hydraulics Division, Proceedings of the ASCE, 1983.

S.C. Cheung, R.C.Y. Koh, "Modeling of Advective Transport and Turbulent Dispersion in Coastal Waters," Report to NOAA, 1985.

SETTLING CHARACTERISTICS OF SEWAGE SLUDGE PARTICLES

Investigators: Robert C.Y. Koh, Norman H. Brooks, Theresa R.F. Wang*

Support: NOAA, Orange County, Los Angeles County

An important parameter governing the fate of particles in sewage sludge discharged into the ocean is the fall velocity of the particles. Preliminary results in conventional settling column experiments show that the apparent fall velocity distributions depend not only on the specific sample (i.e., sampling time and location) but also on initial mixing in the experimental procedures.

Both sedimentation and coagulation contribute to the observed settling column experimental results. A conceptual model including sedimentation, coagulation, and vertical diffusion was postulated to provide an alternate interpretation of observed results which showed through comparison with experiments that the often assumed second order coagulation rate is not the general case and the interpretation of experimental data via a simple fall velocity distribution is not correct.

Future experiments will be designed in such a way as to overcome this inherent difficulty. Coagulation and sedimentation are forced to occur sequentially in a coagulating reactor (flocculator) and a settling chamber. Very high dilution ratio (10000:1) will be used to suppress further coagulation in a settling chamber. An in-line holographic camera system is being constructed to provide a direct method of measuring size, shape and velocity of sludge particles.

Publications:

T. R. Wang, R.C.Y. Koh, N. H. Brooks, "Interpretation of Sludge Sedimentation Measurements," Proceedings of the 5th International Ocean Disposal Symposium, 10-14 September 1984.

*Graduate Student

INFLUENCES ON KELP GROWTH BY A PCB COMPOUND

Investigators: Margaret Carter,* David E. James,** Steven L. Manley, Wheeler J. North

Support: SURF Funds, EQL Funds, Kelco Company, Atlantic Richfield Foundation

Usage of the polychlorobenzene (PCB) class of organic compounds was phased out several years ago because of demonstrated toxicities by the compounds to plants and animals. Unfortunately, PCBs have been utilized for so long and natural degradation processes are so slow, that trace quantities of these toxicants persist in our environment and occur in our various waste discharges. Research on effects of PCBs on microscopic stages in the life cycle of giant kelp Macrocystis (a dominant and ecologically-important seaweed) was initiated as a summer project under the SURF program. A very clear-cut toxic response was found, which has been confirmed by subsequent studies. From this preliminary work it appears that PCBs might have a significant ecological effect in coastal waters of Southern California and that kelp microscopic stages may have good potential as a bioassay organism with a short response time. We are presently seeking outside funding to expand these investigations.

This is a preliminary report of work in progress and as yet no written publication is available for distribution.

*Undergraduate SURF Student
**Graduate Student

SURFACE CHEMICAL AND PHYSICAL BEHAVIOR OF CHRYSOTILE ASBESTOS IN NATURAL WATERS AND WATER TREATMENT

Investigators: Roger C. Bales,* James J. Morgan

Support: Andrew W. Mellon Foundation, Metropolitan Water District of Southern California, American Water Works Association Research Foundation

Chrysotile asbestos fibers enter California waters from physical weathering of magnesium-silicate, serpentine rocks. Chrysotile particles, initially positively charged below pH 8.9 because of their magnesium-hydroxide surface, become negatively charged due to dissolution and adsorption of organic matter. Magnesium release from chrysotile dissolving in 0.1 M inorganic electrolyte at pH 7-10 for up to five days is in excess of the 3:2 Mg:Si to silica molar ratio in the solid. The magnesium release rate exhibits a fractional dependence on hydrogen-ion concentration:

$$r = k_1'[H^+]^{0.24}$$

In terms of a surface site-binding model, the fractional dependence implies that dissolution is limited by a chemical reaction involving less than one adsorbed proton per magnesium ion released. The rate of magnesium release is independent of the anions NO_3^-, Cl^-, HNO_3^-, oxalate or catechol. Oxalate inhibited and catechol slightly enhanced silica release at pH 7.5-8.5; other anions had no systematic effect. Chrysotile's dissolution rate ($10^{-15.7}$ mol/cm^{2}s at pH 8) is consistent with observations on other magnesium silicates and brucite. Catechol adsorption onto chrysotile or aluminum oxide (pH 7.5-8.5) does not reach equilibrium immediately but increases over five days. After one day the adsorption density on chrysotile is 50×10^{-6} mg C/cm^2, approximately one-third of the estimated density for proton exchange. The maximum adsorption density for natural organic matter was near 30×10^{-6} mg C/cm^2 on both chrysotile and aluminum oxide. Chrysotile adsorbs sufficient organic matter within one day to reverse its surface charge. In reservoirs, submicron-sized chrysotile particles coagulate with larger (>2 μm), negatively-charged particles which subsequently settle out. The rate at which freshly-suspended, positively-charged fibers coagulate is at least ten-fold greater than that for aged, negatively-charged fibers. Capture of chrysotile particles in water filtration is enchanced 10-fold or more by incorporating fibers into larger flocs.

*Graduate Student

Publications:

R. C. Bales, Surface Chemical and Physical Behavior of Chrysotile Asbestos in Natural Waters and Water Treatment, Ph.D. Thesis, California Institute of Technology, 1984.

R. C. Bales, D. D. Newkirk, and S. B. Hayward, "Chrysotile Asbestos in California Surface Waters: From Upstream Waters Through Water Treatment," Journal American Water Works Association, 76, 1984, pp. 66-74.

R. C. Bales, J. J. Morgan, "Surface Charge and Adsorption Properties of Chrysotile Asbestos in Natural Waters," Environmental Science and Technology, 19, 1985, pp. 1213-1219.

R. C. Bales, J. J. Morgan, "Dissolution Kinetics of Chrysotile at pH 7 to 10," Geochimica et Cosmochimica Acta, 49, 1985, pp. 2281-2288.

SIMULATION OF PARTICLE COAGULATION MECHANISMS

Investigators: E. John List, Iraklis A. Valioulis,* Henry J. Pearson

Support: NOAA Office of Marine Pollution Assessment, Mellon Foundation

The purpose of this research is to describe the change in the size distribution of suspended particulate matter that arises when such particles collide and adhere to one another. This is an important feature of any analysis of the fate of any particulate matter in fluid suspension. The goal of the research was to find a mathematical description of the processes causing collisions of particles (Brownian motion, fluid straining motions, differential sedimentation) and influencing the success of a collision process (van der Waals' attraction, surface charge, hydrodynamic interactions). The work has had three main thrusts. In one, the collision processes were modeled numerically using a Monte Carlo approach defined by stochastic particle displacements. The collision efficiencies so developed were modified by factors determined by mathematical calculation of the effect of interparticle forces. This technique showed that the equilibrium hypothesis previously used to define steady state size distributions is not appropriate for interacting particles. The second facet of the work was to apply these results to the computation of the actual operation of a sedimentation tank (a piece of equipment used to enhance particle separation). The third problem area concerned the evaluation of the completeness of the kinetic coagulation equation in the evaluation of particle size distributions when the mean number concentration of particles present in suspension is low. This work has developed specific criteria for determination of when number concentrations may be so low as to cause the kinetic coagulation equation to be inadequate.

Publications:

H. J. Pearson, I. A. Valioulis, E. J. List, "Monte Carlo Simulation of Coagulation in Discrete Particle Size Distributions. Part I. Brownian Motion and Fluid Shearing," Journal of Fluid Mechanics, v. 143, 1984, pp. 367-385.

I. A. Valioulis, E. J List, H. J. Pearson, "Monte Carlo Simulation of Coagulation in Discrete Particle Size Distributions. Part II. Interparticle Forces and the Quasi-Stationary Equilibrium Hypothesis," Journal of Fluid Mechanics," v. 143, 1984, pp. 387-411.

*Graduate Student/Post-doctoral Fellow

I. A. Valioulis, E. J. List, "Collision Efficiencies of Diffusing Spherical Particles: Hydrodynamic, van der Waals' and Electrostatic Forces," Advances in Colloid and Interface Science, v. 20, 1984, pp. 1-20.

I. A. Valioulis, E. J. List, "Numerical Simulation of a Sediment Basin. 1. Model Development," Environmental Science and Technology, v. 18, 1984, pp. 242-247.

I. A. Valioulis, E. J. List, "Numerical Simulation of a Sediment Basin. 2. Design Application," Environmental Science and Technology, v. 18, 1984, pp. 248-253.

I. A. Valioulis, E. J. List, "A Numerical Evaluation of the Stochastic Completeness of the Kinetic Coagulation Equation," Journal of the Atmospheric Sciences, v. 41, n. 16, 1984, pp. 2516-2529.

I. A. Valioulis, E. J. List, "Stochastic Modeling of Coagulation," Proceedings, Fourth International Symposium on Stochastic Hydraulics, International Association of Hydraulic Research, University of Illinois, July 31 - August 2, 1984.

C. RISK ASSESSMENT

RISK ASSESSMENT AND MANAGEMENT

Investigators: R. Talbot Page*, Richard McKelvey, Lode Li

Support: Hewlett Foundation, Mellon Foundation

In the past few years, both industry and regulatory agencies have come to use quantified risk assessment. However, current methods of risk assessment are less than satisfactory in several ways. They often are costly and time consuming, may result in vague and unusable estimates, and are difficult to evaluate in the light of later information.

In each of the three studies described below, the central questions are: How does the structure of the market (or committee or group) affect the incentives to undertake research on risk assessment? How strong are the research incentives? (There can be too much as well as too little research on risk assessment.) Is the information pooled or aggregated efficiently?

Last year Drs. Toby Page and Lode Li, EQL economists, working with Professor Richard McKelvey of the Humanities and Social Sciences Division, initiated research on systems of incentives for individuals (and institutions) to assess and manage risks.

Three projects were aided by the Hewlett grant during 1983-84. In the first, the relationship between market structure and the incentives for insurance companies to assess the risks of natural hazards are being investigated. In their model of the duopoly (two company) case, they have found that there can be an incentive to undertake more than the efficient amount of research in an assessment, but to use the information less efficiently, for a reduction in net social benefits.

In the second project, they conducted a laboratory experiment in which participants use both publicly available information and their own private information. They combine the two sources of information to assess the probability of an event. For example, several companies might produce a chemical. Each company has its own private information on the likelihood of toxicity, but augments that information on the basis of publicly observed prices and quantities. If industry production of the chemical is low, then a company may infer that the others' private information points to a higher

*Now at UCLA (since January 1986)

probability of toxicity. But since the public information arises from all the participants' actions, there is the potential problem of feedback and instability as individuals use the public information to supplement their original private information. In the experiment, this problem does arise, but in the laboratory setting, the efficiency of the inference process can be measured and appears surprisingly high, considering the delicacy of the inference problem in the experiment.

In the third and ongoing study, Dr. Page is investigating procedures for eliciting assessments of risk and rewarding the assessors on the basis of performance. It is well known that a particular class of procedures, called proper scoring rules, have dominant strategies for truthful reporting of probability assessments. Part of last year's research on elicitation procedures suggested a link between proper scoring rules and rules of legal liability.

In 1985, Dr. Page began to follow up on this surmise. In work continuing into 1986, Dr. Page is investigating legal rules of liability as incentives for firms in the chemical industry. It now seems clear that the surmise is correct and in fact proper scoring rules can be directly translated into rules of strict liability. More generally, the current work suggests that a principle of legal responsibility, along with a principle of economic efficiency, provide a joint foundation to the theory of incentive compatibility. This further result has practical application because it suggests a way of lowering the fact-finding burden of courts and decreasing incentives to misrepresent in litigants' assessments of risk.

Publications:

Talbot Page, Robert Harris, "A Cost-Benefit Approach to Drinking Water and Cancer," Water Chlorination: Environmental Impact and Health Effects, R. Jolley and R. Cumming, eds., v. 4, 1983.

Talbot Page, "Uncertainty and Policy Formation," Chapter 10 of Ocean Disposal of Municipal Wastewater: Impacts on the Coastal Environment, E. P. Myers, ed., 1983, pp. 611-657.

Talbot Page, "Intergenerational Justice as Opportunity," Energy and the Future, Douglas MacLean and Peter G. Brown, eds. (Maryland Studies in Public Philosophy), 1983.

Talbot Page, "On the Meaning of the Preponderance Test," Law and Contemporary Problems, v. 46, No. 3, Summer 1983, pp. 267-283.

Talbot Page, "On the Meaning of the Preponderance Test in Judicial Regulation of Chemical Hazard," Law and Contemporary Problems, v. 46, Summer 1983.

Talbot Page, Gib Bogle, "Priority Setting for Testing Chemicals," Safety Evaluation and Regulation of Chemicals," February 1983, pp. 106-111.

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Talbot Page, Douglas MacLean, "Risk Conservatism and the Circumstances of Utility Theory," American Journal of Agricultural Economics, v. 65, No. 5, December 1983, pp. 1021-1026.

Talbot Page, John Ferejohn, "Improving Risk Analysis," Contemporary Issues in Risk Analysis, 1984.

Talbot Page, M. D. McCubbins, "A Theory of the Choice of Regulatory Form," Theories on Congress: The New Institutionalism, M. . McCubbins, T. Sullivan, eds., 1984.

Talbot Page, P. Ricci, "A Cost-Benefit Perspective for Risk Assessment," Fundamentals of Risk Benefit Analysis, 1985.

Talbot Page, "Responsibility, Liability, and Incentive Compatibility," Caltech Social Science Working Paper No. 590. November 1985.

Talbot Page, "Pivot Mechanisms in Probability Revelation," Caltech Social Science Working Paper No. 596, December 1985.

Talbot Page, Richard D. McKelvey, "Common Knowledge, Consensus and Aggregate Information," Econometrica, v. 54, No. 1, January 1986, pp. 109-127.

Talbot Page, Matthew McCubbins, "A Theory of Congressional Delegation," Matthew McCubbins, Terry Sullivan, eds., Congress: Structure and Policy, Fall 1986 (forthcoming).

Talbot Page, Lode Li, Richard McKelvey, "Optimal Research for Cournot Oligopolists," Journal of Economic Theory, 1986 (forthcoming).

Talbot Page, Matthew McCubbins, "The Congressional Foundations of Agency Performance," Public Choice, 1986 (forthcoming).

D. RESOURCES AND REGULATION

RESIDENTIAL ENERGY DEMAND AND CONSERVATION

Investigators: Jeffrey A. Dubin

Support: Exxon Education Foundation

During 1985 Dr. Dubin has concentrated his research efforts in the area of mixed econometric/economic models. This approach was first attempted in an analysis of residential energy demand and was developed in his book, Consumer Durable Choice and the Demand for Electricity, North Holland, 1985. To follow up this initial research, Dr. Dubin studied the seasonal demand for electricity in the Pacific Northwest. A two-volume summary of this research (coauthored with Steven E. Henson) is now complete. They have also coauthored a paper on the returns to insulation upgrades. Also in 1985, Dr. Dubin completed a paper on block switching in demand to declining block rates.

Publications:

Jeffrey A. Dubin, Consumer Durable Choice and the Demand for Electricity in "Contributions to Economic Analysis Series," North Holland, 1985.

Jeffrey A. Dubin, "Will Mandatory Conservation Promote Energy Efficiency in the Selection of Household Application Stocks?", The Energy Journal, 1985. "The Seasonal Demand for Electricity in the Pacific Northwest - Volume I, Results and Analysis," with Steven E. Henson. Final Report to Bonneville Power Administration, 1985.

Jeffrey A. Dubin, Steven E. Henson, "The Seasonal Demand for Electricity in the Pacific Northwest - Volume II, Data Preparation Methodology. Final Report to Bonneville Power Administration, 1985.

Jeffrey A. Dubin, Steven E. Henson, "The Returns to Insulation Upgrades: Results from a Mixed Engineering/Econometric Model," Caltech Social Science Working Paper No. 582, submitted to the American Economic Review September 1985.

Jeffrey A. Dubin, "Evidence of Block Switching in Demand Subject to Declining Block Rates - A New Approach," Caltech Social Science Working Paper No. 583, submitted to Land Economics October 1985.

ENERGY POLICY STUDIES

Investigators: James P. Quirk, Roger Noll,* Katsuaki Terasawa,** Donald Lien,*** William Pegram***

Support: Exxon Education Foundation

A major focus of Professor Quirk's recent work has been cost estimation on pioneer high technology projects. One output of this work is a paper written jointly with Dr. Katsuaki Terasawa of the Rand Corporation entitled "Sample Selection and Cost Underestimation Bias in Pioneer Projects," forthcoming in Land Economics, May 1986. The paper shows that under rational updating behavior on the part of project decision-makers will choose to build precisely those projects that have the best chance of exhibiting cost overruns. This is a source of cost overruns that is separate and distinct from inefficiencies in contracting or biases in estimation procedures and is generic to the cost estimation problem.

Another aspect of uncertainty is addressed in "Consumer Surplus under Uncertainty: An Application to Dam-Reservoir Projects," which appeared in Water Resources Research, September 1985. Here the issue is that of identifying an appropriate measure of project benefits when those benefits are uncertain. One of the findings of the paper is that use of the usual consumer surplus measures understates the true benefits of such projects because of an unobserved component of benefits.

Work is also continuing on an ongoing study of price patterns on futures markets, including work by Donald Lien, a graduate student who is completing his dissertation this year at Caltech. Among his research papers are "Profitable Speculation and Linear Excess Demand," Social Science Working Paper No. 521; "Speculative Holdings under Linear Expectation Processes--A Mean-Variance Approach," Social Science Working Paper No. 533; "Speculation and Price Stability under Uncertainty: A Generalization," Social Science Working Paper No. 536.

Another graduate student, William Pegram, is working with Dr. Quirk on a thesis titled, "Design of Government Policy Anticipating Policy Change." Mr. Pegram's thesis committee includes Dr. Roger Noll of Stanford and Professors Dubin, Quirk and Thomas Gilligan of Caltech. The thesis examines the design of federal government policy given that changes in government policy are likely to occur. The focus is how economic and political uncertainty (that could lead to changes in government policy) is addressed in U.S.

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**Rand Corporation
***Graduate Student

government commercialization, procurement, and regulatory activities. Rather than trying to generalize in the abstract regarding these activities, one example of each kind of program will be examined in depth:

commercialization:	photovoltaics
procurement:	5 Air Force weapon systems
regulation:	EPA, with and without compensation of those harmed by regulation

The photovoltaics chapter will appear in The Technology Pork Barrel, edited by Roger Noll and Linda Cohen, to be published by the Brookings Institution.

Publications:

James P. Quirk, "Consumer Surplus Under Uncertainty: An Application to Dam-Reservoir Projects," Water Resources Research, September 1985, pp. 1307-1312.

James P. Quirk, Katsuaki Terasawa, "Sample Selection and Cost Underestimation Bias in Pioneer Projects," Land Economics, May 1986 (forthcoming).

Donald Lien, "Profitable Speculation and Linear Excess Demand," Caltech Social Science Working Paper No. 521, March 1984.

Donald Lien, "Speculative Holdings under Linear Expectation Processes—A Mean-Variance Approach," Caltech Social Science Working Paper No. 533, July 1984.

Donald Lien, "Speculation and Price Stability under Uncertainty: A Generalization," Caltech Social Science Working Paper No. 536, July 1984.

William Pegram, "Design of Government Policy Anticipating Policy Change," Ph.D. thesis (in preparation, 1986).

William Pegram, "Photovoltaics," The Technology Pork Barrel, Roger Noll, Linda Cohen, eds., Brookings Institution (forthcoming).

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA 91125

January 1986

PUBLICATIONS

The dissemination of EQL's work is through various types of publications as described below and listed on the following pages. Note that the lists are roughly chronological within each category with the latest works at the end.

January 1986

ENVIRONMENTAL QUALITY LABORATORY

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ARTICLES*

1	E. J. List	"Energy and the Environment in Southern California," Engineering and Science, California Institute of Technology, v. 35, no. 2, pp. 14-17, November 1971.
A-1	Lester Lees	"Why the Energy Crunch Came in the '70's," Cry California, pp. 29-34, Fall 1972.
A-2	John Holdren	"Energy, the Environment, and Thermonuclear Reactors," Engineering and Science, California Institute of Technology, pp. 10-15, April 1972.
A-3	James E. Krier & W. David Montgomery	"Resource Allocation Information Cost and the Form of Government Intervention," Natural Resources Journal, v. 13, no. 1, pp. 89-105, January 1973. Also Social Science Working Paper #11.
A-4	Fredrick H. Shair & Kenneth L. Heitner	"Theoretical Model for Relating Indoor Pollutant Concentrations to Those Outside," Environmental Science and Technology, v. 8, no. 5, pp. 444-451, May 1974.
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A-6	Kenneth L. Heitner & James E. Krier	"An Approach to Air Quality Management Standards," Journal of the Air Pollution Control Association, v. 24, no. 11, pp. 1039-1043, November 1974.
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A-8	Alan Hirshberg & Richard Schoen	"Barriers to the Widespread Utilization of Residential Solar Energy: The Prospects for Solar Energy in the U.S. Housing Industry," Policy Sciences 5, pp. 453-468, 1974.
A-9	W. David Montgomery	"Artificial Markets and the Theory of Games," Public Choice, v. 18, pp. 25-40, Summer 1974.
A-10	Lester Lees	"Energy Conservation: Will it Work?" Engineering and Science, California Institute of Technology, pp. 3-9, April-May 1975.
A-11	Alan M. Schneider	"Elasticity of Demand for Gasoline," Energy Systems and Policy, v. 1, no. 3, pp. 277-285, 1975.
A-12	Roger G. Noll	"Information, Decision-Making Procedures, and Energy Policy," American Behavioral Scientist, v. 19, no. 3, pp. 267-278, January-February 1976. Also Social Science Working Paper #97.

*Articles are free in limited number while supply lasts.

A-13	W. David Montgomery	"Separability and Vanishing Externalities," The American Economic Review, v. 66, no. 1, pp. 174-177, March 1976. Also Social Science Working Paper #74.
A-14	D. J. McKay	"Pricing Policies for Electricity Supply," New Zealand Engineering, v. 30, no. 12, pp. 357-360, 15 December 1975.
A-15	William R. Goodin	"A Numerical Simulation of the Sea Breeze in the Los Angeles Basin," Reprinted from preprint volume: Conference on Coastal Meteorology, pp. 5-7, September 21-23, 1976.
A-16	W. R. Goodin, G. J. McRae & J. H. Seinfeld	"Validity and Accuracy of Atmospheric Air Quality Models," Reprinted from preprint volume: Third Symposium on Atmospheric Turbulence, Diffusion, and Air Quality, pp. 366-373, October 26-29, 1976.
A-17	David G. Elliott	"Comparison of Geothermal Power Conversion Cycles," Eleventh Intersociety Energy Conversion Engineering Conference, 7 pp., September 1976.
A-18	John Trijonis, Ted Peng, Gregory McRae & Lester Lees	"Oxidant and Precursor Trends in the Metropolitan Los Angeles Region," for presentation at The International Conference on Photochemical Oxidant and Its Control, pp. 1-13, Raleigh, North Carolina, September 1976.
A-19	Tracy R. Lewis	"Monopoly Exploitation of an Exhaustible Resource," Journal of Environmental Economics and Management, v. 3, pp. 198-204, 1976.
A-20	Martin Goldsmith	"Geothermal Development and the Salton Sea," Energy, v. 1, pp. 367-373, 1976.
A-21	Tracy R. Lewis	"Optimal Fishery Management under Conditions of Uncertainty," Economic Impact of Extended Fisheries Jurisdiction, Lee G. Anderson, ed., pp. 349-378, 1977.
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A-31	Norman H. Brooks	Testimony at Hearings on Modification of Secondary Treatment Requirements for Discharges into Marine Waters, before the Sub-Committee on Water Resources of the Committee on Public Works and Transportation, House of Representatives, (95-54) pp. 84-102. Includes "Secondary Treatment Waivers and Ocean Outfalls" and "An Overview of the Functional Design of Ocean Outfalls for Wastewater Discharge." May 24 and 25, 1978.
A-32	Gregory J. McRae, William R. Goodin & John H. Seinfeld	"Development of a Second-Generation Airshed Model for Photochemical Air Pollution," Fourth Symposium on Turbulence, Diffusion and Air Pollution, Reno, Nevada, American Meteorological Society, Boston, Mass., pp. 389-396, January 15-18, 1979.
A-33	Tracy R. Lewis, Steven A. Matthews & H. Stuart Burness	"Monopoly and the Rate of Extraction of Exhaustible Resources: Note," The American Economic Review, v. 69, no. 1, pp. 227-230, March 1979. Also Social Science Working Paper #137.
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A-35	William R. Goodin, Gregory J. McRae & John H. Seinfeld	"A Comparison of Interpolation Methods for Sparse Data: Application to Wind and Concentration Fields," Journal of Applied Meteorology, v. 18, no. 6, pp. 761-771, June 1979.
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A-37	Glen R. Cass	"On the Relationship Between Sulfate Air Quality and Visibility with Examples in Los Angeles," Atmospheric Environment, v. 13, pp. 1069-1084, 1979.
A-38	Andrew H. Falls, Gregory J. McRae & John H. Seinfeld	"Sensitivity and Uncertainty of Reaction Mechanisms for Photochemical Air Pollution," International Journal of Chemical Kinetics, v. XI, pp. 1137-1162, 1979.
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A-40	John H. Seinfeld & Gregory J. McRae	"Use of Models to Establish Source-Receptor Relationships and Estimate Relative Source Contributions of NO_x to Air Quality Problems," Technical Symposium on the Implications of a Low NO_x Vehicle Emission Standard, Reston, Virginia, U.S. Environmental Protection Agency, 25 pp., May 2-4, 1979.
A-41	Gregory J. McRae	"Mathematical Modeling of Photochemical Air Pollution," Conference, Proceedings of Society and Aerospace Technology Workshop, American Institute of Aeronautics and Astronautics, held in Los Angeles, 11 pp., November 15, 1980.
A-42	William R. Goodin, Gregory J. McRae & John H. Seinfeld	"An Objective Analysis Technique for Constructing Three-Dimensional Urban-Scale Wind Fields," Journal of Applied Meteorology, v. 19, no. 1, pp. 98-108, January 1980.

A-43	William Brownlie & William M. Brown	"Effects of Dams on Beach Sand Supply," Coastal Zone '78, Symposium on Technical, Environmental, Socioeconomic and Regulatory Aspects of Coastal Zone Management, San Francisco, California, American Society of Civil Engineers, v. 3, pp. 2273-2287, March 14-16, 1978.
A-44	Brent D. Taylor	"Sediment Management for Southern California," Coastal Zone '78, Symposium on Technical, Environmental Socioeconomic and Regulatory Aspects of Coastal Zone Management, San Francisco, California, American Society of Civil Engineers, v. 3, pp. 2259-2264, March 14-16, 1978.
A-45	Gregory J. McRae	"A Simple Procedure for Calculating Atmospheric Water Vapor Concentration," Journal of the Air Pollution Control Association, v. 30, no. 4, p. 394, April 1980.
A-46	Howard M. Liljestrand & James J. Morgan	"Error Analysis Applied to Indirect Methods for Precipitation Acidity," Tellus 31, v. 5, pp. 421-431, 1979.
A-47	James E. Krier & Robert B. Bell	"Old Economics and New Environmental Controls," Stanford Lawyer, v. 15, no. 1, pp. 15-20, 1980.
A-48	Linda Cohen	"Innovation and Atomic Energy: Nuclear Power Regulation, 1966-Present," Journal of Law and Contemporary Problems, v. 43, no. 1, pp. 67-97, 1980.
A-49	William M. Brown, III & Brent D. Taylor	"Recent Erosion in the San Gabriel Mountains," American Society of Civil Engineers, Fall Convention and Exhibit, San Francisco, California. Preprint 3024, pp. 1-16, October 17-21, 1977.
A-50	George A. Jackson	"Marine Biomass Production Through Seaweed Aquaculture," Biochemical and Photosynthetic Aspects of Energy Production, Academic Press, Inc., pp. 31-58, 1980.
A-51	H. Stuart Burness, W. David Montgomery & James P. Quirk	"The Turnkey Era in Nuclear Power," Land Economics, v. 56, no. 2, pp. 188-202, May 1980. Also Social Science Working Paper #175.
A-52	H. Stuart Burness, W. David Montgomery & James P. Quirk	"Capital Contracting and the Regulated Firm," The American Economic Review, pp. 342-354, June 1980.
A-53	Glen R. Cass & Fredrick H. Shair	"Transport of Sulfur Oxides within the Los Angeles Sea Breeze/Land Breeze Circulation System," Conference Papers: Second Joint Conference on Applications of Air Pollution Meteorology and Second Conference on Industrial Meteorology, New Orleans, La., American Meteorological Society, Boston, Mass., pp. 326-327, 24-27 March 1980.
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A-55	Robert W. Hahn	"An Assessment of the Determination of Energy Needs: The Case of Nuclear Power," Policy Sciences 13, pp. 9-24, 1981.
A-56	William R. Goodin, Gregory J. McRae & John H. Seinfeld	Reply to Comments on "A Comparison of Interpolation Methods for Sparse Data: Application to Wind and Concentration Fields," Journal of Applied Meteorology, v. 20, pp. 92-94, 1981.

A-57	J. W. Tilden, V. Costanza, G.J. McRae & J.H. Seinfeld	"Sensitivity Analysis of Chemically Reacting Systems," in Modelling of Chemical Reaction Systems, K.H. Ebert, P. Deuflhard and W. Jagers, eds., Springer-Verlag Series in Chemical Physics, 18, Springer-Verlag, New York, pp. 69-91, 1981.
A-58	Glen R. Cass	"Sulfate Air Quality Control Strategy Design," Atmospheric Environment, v. 15, no. 7, pp. 1227-1249, 1981.
A-59	Glen R. Cass & Gregory J. McRae	"Minimizing the Cost of Air Pollution Control," Environmental Science and Technology, v. 15, no. 7, pp. 748-757, July 1981.
A-60	M. H. Conklin, G. R. Cass, L.C. Chu & E. S. Macias	"Wintertime Carbonaceous Aerosols in Los Angeles: An Exploration of the Role of Elemental Carbon," in E.S. Macias and P.M. Hopke, eds., Atmospheric Aerosol:Source/Air Quality Relationships, 180th ACS National Meeting, Las Vegas, Nevada, August 27-29, 1980, ACS Symposium series 167, pp. 325-250, American Chemical Society, Washington, D. C., 1981.
A-61	G. R. Cass, P. M. Boone & E. S. Macias	"Emissions and Air Quality Relationships for Atmospheric Carbon Particles in Los Angeles," in G.T. Wolff and R.L. Klimisch, eds., Particulate Carbon: Atmospheric Life Cycle, Plenum Press, New York, 1981.
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A-66	James W. Tilden & John H. Seinfeld	"Sensitivity Analysis of a Mathematical Model for Photochemical Air Pollution," Atmospheric Environment, v. 16, no. 6, pp. 1357-1364, 1981.
A-67	G. J. McRae, F.H. Shair & J.H. Seinfeld	"Convective Down Mixing of Plumes in a Coastal Environment." Journal of Applied Meteorology, v. 20, no. 11, pp. 1312-1324, November 1981.
A-68	Norman H. Brooks & James E. Krier	"Alternative Strategies for Ocean Disposal of Municipal Wastewater and Sludge." Presentation at a public hearing before the Subcommittee on Oceanography and the Subcommittee on Fisheries and Wildlife Conservation and the Environment of the Committee on Merchant Marine and Fisheries, U.S. House of Representatives, 38 pp., June 4, 1981; also presented at a public hearing before the Subcommittee on Investigations and Oversight, Committee on Public Works and Transportation, U.S. House of Representatives, 1981 at Los Angeles. Also appears in Use of the Ocean for Man's Wastes, Engineering and Scientific Aspects, Proc. of a Symposium June 23-24, 1981, at Lewes, Delaware, published by Marine Board, National Research Council, Washington, D.C., Appendix A, pp. 271-295, 1981.

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